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Research on displacement monitoring based on laser spot identification

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Abstract

It is difficult to monitor the displacement of large structures accurately in real time for the health monitoring of structures. We studied a laser displacement monitoring system. When the inclination of the structure is negligible, it can achieve real-time monitoring of the horizontal displacement of the structure precisely. The system is composed of a laser transmitter, a receiver board and a camera. The laser transmitter is fixed on the datum plane. Both the camera and the receiver board are fixed on the structure to be monitored. When the structure has horizontal displacement, that camera monitors the position variation of the laser spot on the receiver board. The actual displacement of the structure is obtained through the camera's built-in program. To evaluate the accuracy of the system, we performed two sets of model experiments and obtained the conclusion by comparing the experimental data, determining that our laser displacement monitoring system can monitor horizontal displacement with a high degree of accuracy.

Keywords: Health monitoring; Horizontal displacement monitoring; Laser displacement monitoring system

Introduction

Structure displacement monitoring is an important topic in the field of structural health monitoring. Traditional methods of displacement monitoring of large structures rely mainly on total station, displacement sensors, accelerometers or GPS. However, the total station is greatly restricted by surroundings and cannot monitor the displacement in real time. Displacement sensors should be installed near a fixed reference point, which is difficult in actual displacement monitoring of large structures.

Using the quadratic integral, accelerometers still cannot obtain complete information about the displacement of the structure, which leads to low accuracy. A laser transmitter, a receiver board and a camera constitute a whole system. As shown in Fig. 1, the laser transmitter is fixed on the datum level [2]. The camera and receiver board, which are encapsulated together, are fixed on a point of the structure that needs to be monitored [3]. When the structure undergoes horizontal displacement, the camera monitors the

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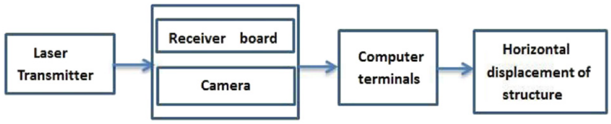

Fig. 1. The schematic diagram of the laser displacement monitoring system.

position variation of the laser spot on the receiver board [6]. The position data are transformed into the actual displacement of the structure by the camera's built-in program. This method to monitor structure displacement is highly specific and effective.

General information

The schematic diagram of the laser displacement monitoring system is shown in Fig. 1 [7]. The laser transmitter is fixed on the datum level; the receiver board is fixed on the structure; [1] the camera and the receiver board are relatively static. The camera is marked with accurate calibration grid paper, which can transform pixel coordinates into a functional relationship of the actual coordinates of the laser spot on the receiver board. The receiver device is fixed on the structure rigidly.

Because it is small compared to the whole structure, the receiver device can be treated as a point fixed on the structure, which is the target monitoring point of the structure.

When the target point of the structure moves from (X_0, Y_0) to (X_1, Y_1), it has a horizontal displacement ΔV. The projection of ΔV on the x and y axes is denoted by $\Delta X'$ and $\Delta Y'$, respectively. Fig. 2 shows that the actual spatial position of the laser spot does not change, whereas the relative position of the light spot on receiver board changes, which is what the camera is monitoring. Assuming the corresponding moving distances are ΔX and ΔY on the x and y axes, respectively, using the simple mathematical relationship, the following formulas can be obtained:

$$\Delta X = |\Delta X'| = X_1 - X_0 \tag{1}$$

$$\Delta Y = |\Delta Y'| = Y_1 - Y_0 \tag{2}$$

Consider the following plane conditions in Fig. 3, where the structure changes in a small dip angle (Fig. 4).

The displacement of the structure and the camera are $\Delta X = X1'\cos\alpha - X1$ and $\Delta X = X1' - X1$, respectively. The error is $\delta = X1' - X1'\cos\alpha$. Compared to the whole structure, the displacement can be considered to be small. Given the values of α of 0.5°, 1°,1.5°, 2°, 2.5°, the error, δ, can be obtained. The results are shown in Table 1.

Thus, when the angle variation is less than or equal to 2.5°, the horizontal displacement of the structure can be considered as $\Delta X = X1' - X1$, with absolute deviation of less than 0.05 mm. In this way, the monitoring accuracy reaches 0.1 mm

The displacement in space is similar to that on the plane. In the case of a small rotation, the monitoring system can also capture the horizontal displacement accurately.

Statics experiment

The experimental setup includes one laser transmitter, one spiral regulator, a piece of receiver board and one camera. The spiral regulator is used to precisely control the actual horizontal displacement of the laser. During the experiment, the camera collects the

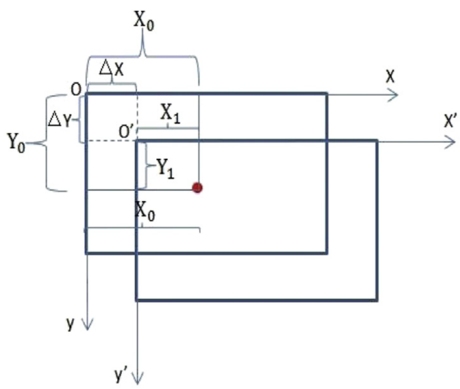

Fig. 2. Geometric relationship in plane motion.

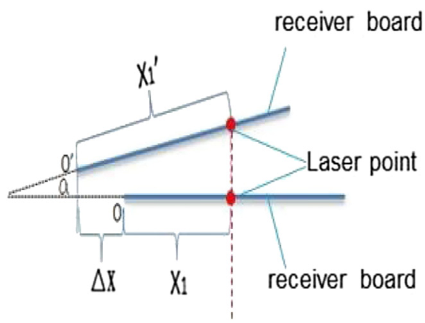

Fig. 3. Geometric relationship in a small dip.

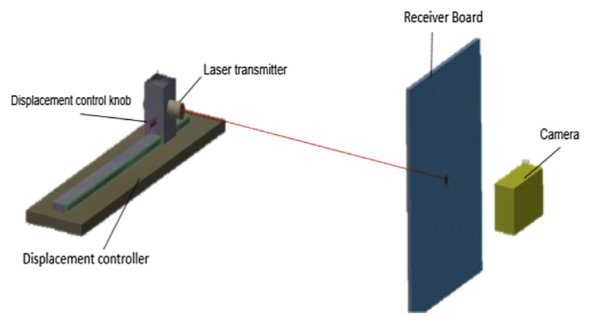

Fig. 4. Equipment diagram for the statics displacement experiment.

Table 1
Deviation at different angles.

$\alpha/°$	0.5	1	1.5	2	2.5
δ/mm	0.0019	0.0076	0.0171	0.0303	0.0476

spot image generated by the laser from the receiver board. When turning the screw adjuster, the actual displacement of the transmitter, i.e., the horizontal displacement of structure, can be converted through the camera's built-in program. The camera we used in this experiment is a Baumer VSXF100M03W10 EP XF-100. Fig. 5 illustrates the linear fitting results between the actual and the measured values.

The average error between the actual displacement and the measured displacement is approximately 0.058 mm. This demonstrates that the camera can accurately monitor the structure's displacement.

Dynamic experiment

The device is shown in Fig. 6. A laser transmitter is fixed at the endpoint of the equal strength beam. A receiver board is installed on a table, which is assumed

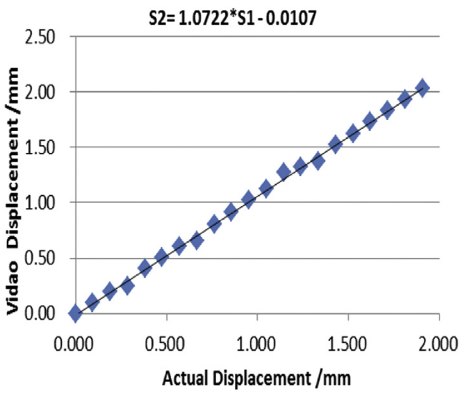

Fig. 5. Fitting a straight line of the actual displacement and the video displacement.

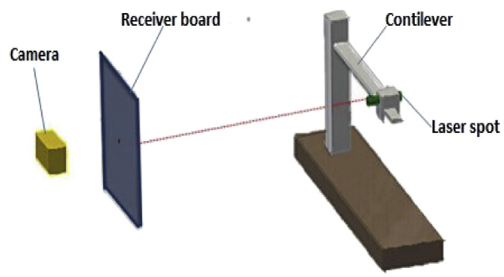

Fig. 6. Equipment diagram for the dynamic experiment.

stationary. A laser displacement sensor is placed beneath the laser transmitter for the control group [4].

Once the laser is generated, the camera collects the facula image from the receiver board, then changes the measured displacement into the actual displacement variation of the facula by means of the camera's built-in program, which can be further converted into the displacement variation of the beam. The laser displacement sensor records the beam's real vibration simultaneously. The camera we use in this dynamic experiment is a Baumer VSXF100M03W10EP XF-100, which can record the change of the laser spot displacement in the form of a video, and then change the video into a series of pictures, in which the camera can monitor the displacement of the laser point to achieve dynamic and real-time displacement monitoring [5].

In light conditions, the collection frequencies of the camera and sensor are 15 Hz and 1000 Hz. Fig. 7 shows the results of displacement by the laser sensor; Fig. 8 shows the data measured by the camera. Fig. 9 reflects the fitting result between Figs. 7 and 8.

Table 2 shows the monitoring error of the camera under different frequencies and light conditions. As the camera's frequency increases, the monitoring error decreases significantly. The monitoring accuracy of camera under dark conditions is better than under light

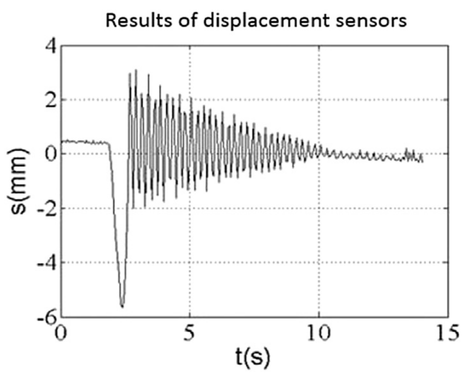

Fig. 7. Displacement monitoring results by displacement sensors.

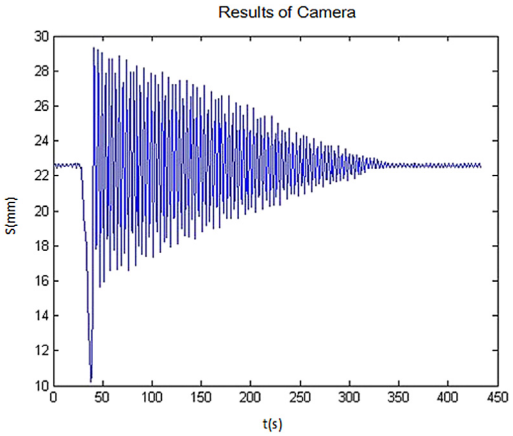

Fig. 8. Displacement monitoring results by camera.

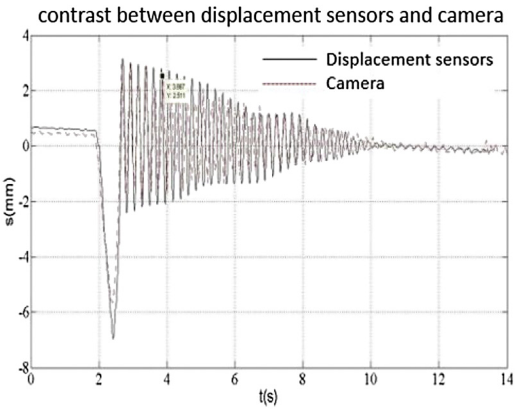

Fig. 9. The fitting result between the sensor and camera.

Table 2
Monitoring the deviation at different frequencies.

The monitoring error under different light condition and camera frequency					
Light conditions			Dark conditions		
15 Hz	25 Hz	35 Hz	15 Hz	25 Hz	35 Hz
0.981	0.691	0.341	0.577	0.211	0.102

conditions. The reason is that laser spot is little affected by some external factors under dark conditions.

Under dark conditions, the frequency of the camera is set to 35 Hz, and the error is only 0.102 mm, which illustrates that the camera can accurately monitor the variation of displacement in real time.

Conclusions

The two simulation experiments demonstrate that high accuracy horizontal displacement monitoring can be achieved using this system. The system is economical and can operate round-the-clock, monitoring stably under different climatic and time conditions. However, the structure's obvious inclination with the increase of the dip angle and monitoring deviation requires further research. With the improvement of the system optimization of integration, the laser displacement monitoring system can play an important role in the displacement monitoring of important structures in the future.

Acknowledgment

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References

[1] Jo Hongki, Sung-Han Sim, Andrzej Tatkowski, B.F. Spencer Jr., Mark E. Nelson, Feasibility of displacement monitoring using low-cos Tgps receivers, Struct. Control Health Monit. 20 (9) (September 2013) 1240–1254.

[2] Lei Yu, Aihu Song, Automatic monitoring of horizontal displacement in deep foundation pit, in: 2012 International Conference on Systems and Informatics, ICSAI 2012, 515–518, 2012, 2012 International Conference on Systems and Informatics, ICSAI2012.

[3] J. Li, L. Li, Deep horizontal displacement measurement technology in the application of foundation pit excavation, Adv. Mater. Res. 671–674 (2013) 363–367. Construction and Urban Planning.

[4] Huang Ming, Xiuren Ge, Jun Liu, Four Kinds of Statistical models of Dam Vertical Displacement Monitoring Data Analysis, Yangtze River Scientific Research Institute, Feb.2001, pp. 37–40.

[5] Shi Yun, Shi Chen, Cangxu Feng, Shiding Wang, A new equipment for geological disaster monitoring-laser micro-displacement monitoring system, Chin. J. Geol Hazard Control (Jan.2002) 72–73.

[6] Yimin Wu, Kangcheng Lv, Zheng Yingren, Research for real-time displacement monitoring system around deep foundation, J. Xi'an Univ. Architecture & Technology (Natural Sci.) (Jan.2006) 192–198.

[7] Han Yongwen, Liping Yang, Zhonghu Lv, Xiaofei Zhang, Research of laser dimensional displacement monitoring device, Electron. Technol. (Dec.2012) 42–44.